CO3-1 Basic Research for Sophistication of High-power Reactor Noise Analysis

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INTRODUCTION: Reactor noise for high-power reactors were actively measured in the 1960's and 1970's. The major focuses of those researches were for the abnormality diagnosis or the output stabilization diagnosis, and almost researchers were in the field of system control engineering or instrumentation engineering. High-power reactor noise measurements for dynamics' analysis of reactivity change, reactivity feedback or reactor characteristics itself were few in the time (1960's and 1970's), because of the powerless measurement system. In this research, we plan to measure KUR's output with present-day measurement system and plan to analyze with several analysis methods. The results of this work will supply some knowledges and technics in the aspect of sophistication of reactor noise analysis or simulation methods.

In this year, we just started this research after 3years waiting for KUR's operation resuming. The experimental work was done in 30th January 2018. The allocated time for the experiment (that is consistent with the objective of this work) was only 1.5 hour, and the condition was far from what we hoped, because of the administrative problem and the following waiting experimental run (those were not of me!). However, some results were acquired from the bad-condition experiment, and I report those in this report paper.

EXPERIMENTS: In this experiment, the output signal was lined from the control console of KUR. The target signals were of the fission chamber #1 & #2. The signals were binarized in the control console as 4V/0.5 μ sec-TTL signals. The signal was measured by a time-series measurement system (HSMCA4106_LC: ANSeeN Inc.). A schematic view of the measurement is shown in Fig.1.

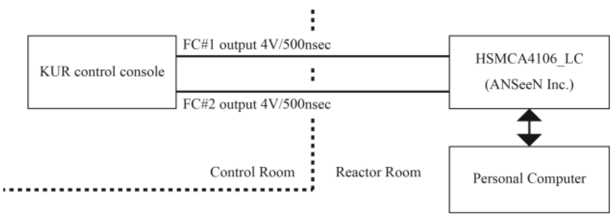

Fig. 1. Schematic view of the measurement.

The experimental condition is shown in Table.1. The allocated time for each condition was only 10 – 30 minutes, and the control rods were occasionally moved in the period of the measurements. (We requested NOT to move the control rods in the measurements' period, however the request was rejected by the operation staff for the output adjustment.)

Table 1. Experimental condition

KUR power [W_{th}]	Measurement Time [sec]	FC#1 Position [%]	FC#2 Position [%]
20	700	14	19
1k	800	33	38
100k	1,800	51	62

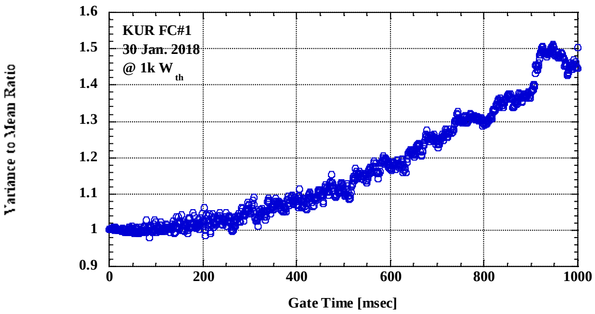

Fig.2. (a) Analyzed result of FC#1 for 1kW_{th} operation

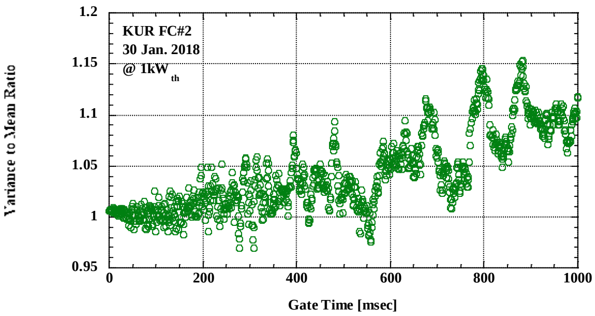

Fig.2. (b) Analyzed result of FC#2 for 1kW_{th} operation

RESULTS: Typical results of the experiments are shown in Fig.2 (a) and (b). Fig.2(a) shows an analyzed results of fission chamber #1 signal for 1kWth operation with the Feynman-α analysis, and Fig.2(b) shows an analyzed results of fission chamber #2 signal for 1kWth operation with the Feynman-α analysis. The vertical axis is the Variance to Mean Ratio, and the horizontal axis is the gate time. The analysis was done with the "bunching method". The Variance to Mean Ratio increase with the gate time width expanding, and the ratio have fine structures. The increasing trend is estimated to be of the control rod moving, and the fine structures are estimated to be a characteristic of the "bunching method". We are planning to apply another analysis method in the next experiments at KUR.

CO3-2 Irradiation Experiments of ^{237}Np and ^{241}Am Foils for Fission Reactions by 14 MeV Neutrons

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INTRODUCTION: Solution for the issue on the accumulation of minor actinides (MAs) from the operation of light water reactors (LWRs) has been proposed by reducing the amount of MA by the transmutation with high-energy neutrons before the disposal into underground. Among of MAs, nuclides of ^{237}Np and ^{241}Am constitute high radiotoxicity in the spent fuel from LWR and become a main target for the transmutation. For attaining the transmutation system, the accuracy of the nuclear data library of MA is regarded as quite important at a hard spectrum core because the accuracy influences the transmutation amount. However, the nuclear data library needs improvement for the MA and requires the accumulation of differential and integral experiments. Previous studies [1]-[3] were conducted for acquiring the fission reaction rate of ^{237}Np and ^{241}Am in integral experiments with thermal core. For the transmutation system, the experiment is also requisite in the high-energy neutrons. Accordingly, in this study, special attention was paid for the acquisition of ^{237}Np/^{235}U and ^{241}Am/^{235}U fission reaction rate ratios by the irradiation experiments with 14 MeV neutrons at the Kyoto University Critical Assembly (KUCA).

EXPERIMENTAL SETTINGS: For the irradiation experiments with 14 MeV neutrons, an irradiation hole was constituted in front of the tritium target at the KUCA-A core surrounding iron reflector, as shown in Fig. 1. ^{237}Np or ^{241}Am foil was set in the back-to-back (BTB) type double fission chamber with ^{235}U foil for normalization. By the insertion of objective foil (^{237}Np or ^{241}Am) and reference foil (^{235}U) closely into the BTB fission chamber and the irradiation at the same time, the fission counts could be regarded as the fission reaction rates under same neutron spectrum and flux. The results of the experiments were accumulated as an index of the fission reaction rate ratio of objective foil to reference foil. 14 MeV neutrons were prepared by the deuteron beam injection onto the tritium target. Deuteron accelerator was operated under 10 Hz of pulsed repetition, 80 μs of pulsed width and 0.1 mA of beam current. The irradiation time was for 2 hours.

RESULTS: The pulsed height distributions from the BTB fission chamber were obtained as shown in Fig. 2, and revealed very poor signals about fission reactions for all foils (discrimination channel between fission reactions and others: 125, 89 and 87 for ^{235}U, ^{237}Np and ^{241}Am, respectively). Although the effective signals indicating the fission reactions were very few, both fission reaction rate ratios were obtained in both foils, as shown in Table 1. Here, in the comparison of fission cross sections at 14 MeV neutrons between ^{235}U, ^{237}Np and ^{241}Am, the values are 2.053, 2.148 and 2.710 barns in JENDL-4.0. Thus, measured fission reaction rate ratio showed the possibility to be valid because the value of fission reaction rate ratio could be predicted near 1.0 from the division of fission cross section by ^{237}Np/^{235}U and ^{241}Am/^{235}U. An improvement of 14 MeV neutron yield is needed to be higher measurement accuracy of MA irradiation experiments. Since spectrum indices of ^{37}Np/^{235}U and ^{241}Am/^{235}U fission reaction rate ratios were significantly obtained at 14 MeV neutrons in the experiments, numerical analyses are expected to be conducted to verify uncertainty of the MA cross sections in nuclear data library.

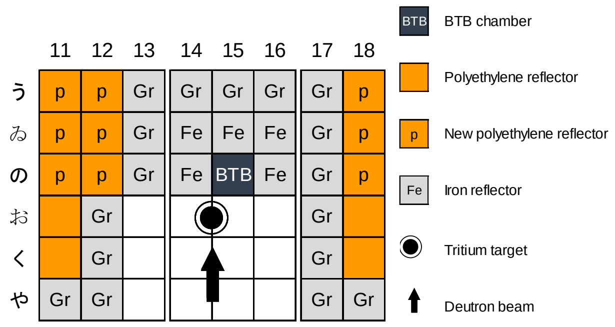

Fig. 1. Experimental settings of MA irradiation.

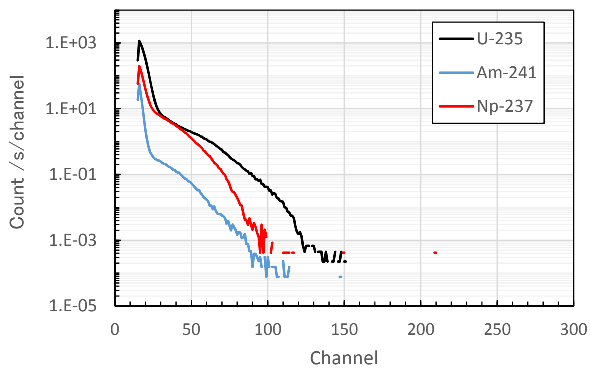

Fig. 2. Pulsed height from BTB fission chamber.

Table 1. ^{237}Np/^{235}U and ^{241}Am/^{235}U fission reaction rate ratios.

Nuclide	Fission reaction rate ratio to ^{235}U
^{237}Np	0.8141
^{241}Am	1.1501

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CO3-3 Neutronics of U-Fueled and Pb-Zoned Core in Accelerator-Driven System

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INTRODUCTION: At the Kyoto University Critical Assembly (KUCA), the uranium (U)-fueled and lead (Pb)-zoned core (A(1/8"p60EUEU<1/8"Pb40p20EU EU>1/8"p60EUEU)) was newly comprised to evaluate the reactor characteristics of the accelerator-driven system (ADS), as shown in Fig. 1. In this core, two types of fuel rods were used for modeling the Pb-cooled reactor. The fuel rod containing Pb (f: 1/8"Pb40p20EUEU) was placed at the center region of the core and composed of 40 time repetition of a unit cell by 1/8" highly-enriched uranium (HEU) thick and 1/8"Pb thick plates sandwiched upper and lower parts by 10 time repetition of another unite cell by 1/8"HEU and 1/8"p plates. Further, the other fuel rod (F: 1/8"p60EUEU), composed of 60 time repetition of a unit cell by 1/8"HEU thick and 1/8"p (p: polyethylene moderator) thick plates, was used to surround the Pb-loaded fuel rods. In a series of ADS experiments, the subcriticality was varied by substituting the fuel rod for the polyethylene reflector, in order to provide deep subcriticality ranging between about 3,000 and 7,000 pcm; k_{eff} = 0.97 to 0.93).

EXPERIMENTS: The subcriticality measurement was carried out in the ADS experiment by the pulsed neutron source method with the use of 14 MeV neutrons (pulsed repetition 100 Hz, pulsed width 80 μs and intensity 0.3 mA). The subcriticality was obtained by the α-fitting method, the Feynman-α method and the area ratio method, as shown in Table 1. From the results in Table 1, the BF_3#2 detector response revealed good agreement with reference result, and conversely BF_3#3 was compared with reference one, giving a large discrepancy caused by a closing location to 14 MeV neutron source. The irradiation experiment was carried out to obtain the reaction rate distribution with the use of indium (In) wire (1.5 mm diameter and 700 mm long) in the subcritical core together with 14 MeV neutrons. The deuteron accelerator was operated at pulsed repetition 100 Hz, pulsed width 80 μs and intensity 0.3 mA for 1 hour. The ^{115}In $(n, \gamma)^{116}$In reaction rate distribution is shown in Fig. 2, demonstrating the thermal neutron flux information on normal fuel (F) and U-Pb zoned (f) core configuration.

CONCLUSION: The ADS experiments with 14 MeV neutrons were carried out in the KUCA A core (U-fueled and Pb-zoned core), and neutronics of U-Pb core were investigated through the measurements of static and kinetic parameters in the reactor physics.

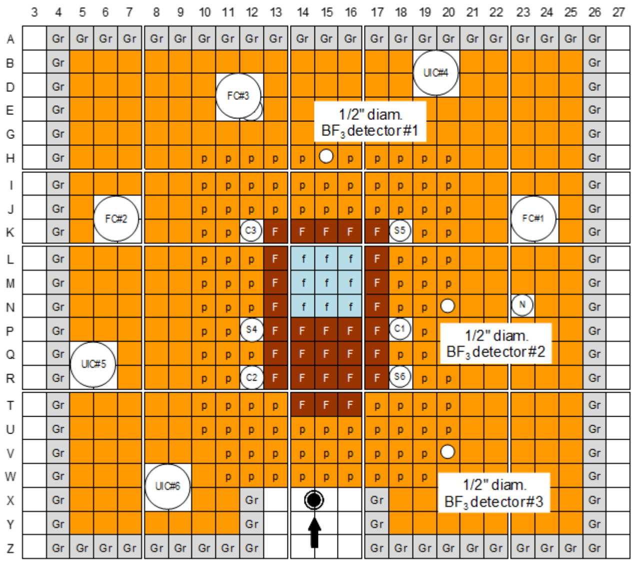

Fig. 1 Top view of configuration of U-fueled and Pb-zoned core.

Table 1 Result of subcriticality measurement in α-fitting method [pcm].

Reference (MCNP)	BF_3 #1	BF_3 #2	BF_3 #3
3397 ± 13	3658 ± 167	3812 ± 198	4385 ± 1319
5032 ± 13	5252 ± 108	5285 ± 88	7230 ± 333
7491 ± 13	7626 ± 237	7613 ± 166	11326 ± 515

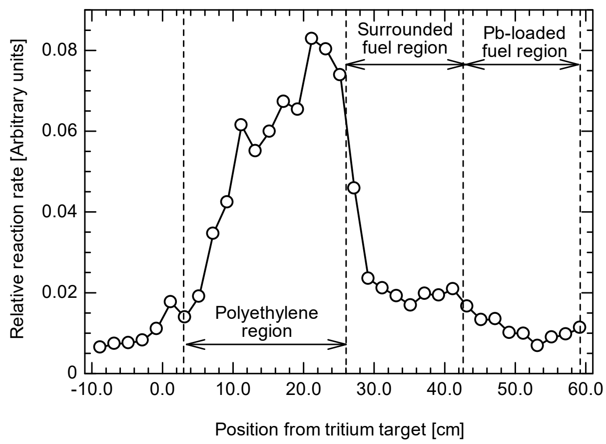

Fig. 2 Measured results of ^{115}In$(n, \gamma)^{116}$In reaction rates along (16, 17 – Z, L) in Fig. 1.

ACKNOWLEDGEMENT: This research was conducted under the collaboration research between INEST/CAS, China and Research Reactor Institute, Kyoto University.

CO3-4 Subcriticality Measurement by Advanced Rossi-α Fitting in Accelerator-Driven System

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INTRODUCTION: A new polyethylene-moderated A-core has been designed at Kyoto University Critical Assembly (KUCA) for a subcritical reactivity estimation experiment. UNIST students carried out the experiment to apply noise analysis methods for estimating the new core's subcriticality. Among the noise analysis methods, Rossi-alpha, Feynman-alpha, and advanced Rossi-alpha methods have been applied for subcriticality estimation. These three methods obtain a decay constant α using their fitting curve formulae and calculate a reactivity ρ from α using the delayed neutron fraction β and neutron generation time Λ. The β and Λ were given by an independent experiment carried by the KUCA professional staffs.

EXPERIMENTS: The core configuration is shown in Fig. 1. As shown in Fig. 1, "F" is a normal fuel assembly composed of uranium and polyethylene, "f" is a special fuel assembly composed of uranium, polyethylene, and lead, "p" is a polyethylene moderator assembly, "C1~C3" are control rods, "S4~S6" are safety rods, "FC#1~FC#3" are fission chambers, and "N" is an Am-Be neutron source located outside the core. The only difference between normal and special fuel assemblies is the presence of lead for the neutron spectrum control. The detector signals from the FC#1 has been used for analysis.

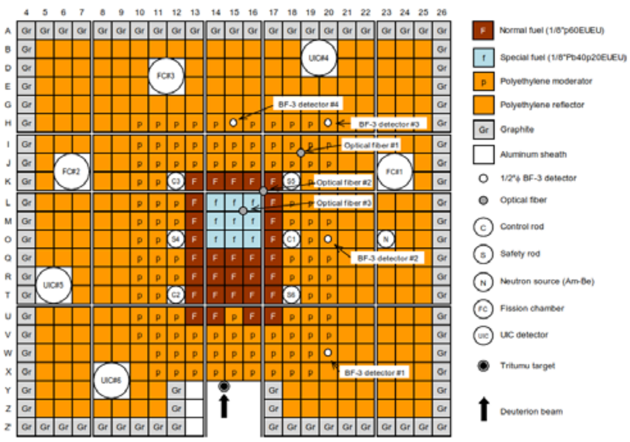

Fig. 1. KUCA core configuration

RESULTS: Table 1 summarizes the analysis results of the noise analysis methods using the FC#1's detector signals. The reference reactivities were provided by an independent experiment carried by the KUCA professional staffs. Figs. 2-4 show the Rossi-alpha, Feynman-alpha, and advanced Rossi-alpha fitting results.

Table 1. Analysis results using noise analysis methods

Method	Rossi-alpha	Feynman-alpha	Advanced Rossi-alpha
α	1766 ± 45	786 ± 45	1863 ± 17
ρ	-5028 ± 150	-1766 ± 151	-5351 ± 56
*Ref. ρ	-5211 ± 14	-1646 ± 40	-1646 ± 40
ρ error	-3.5 ± 2.9	7.3 ± 5.4	2.7 ± 0.9

*Reference ρ provided by the KUCA staff.

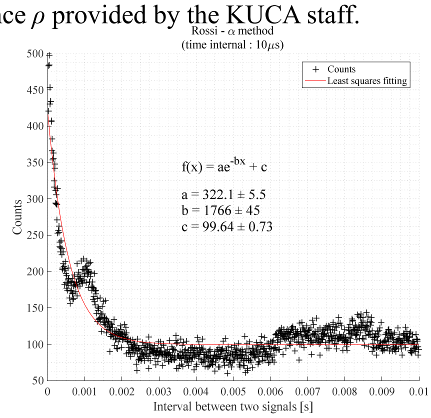

Fig. 2. Rossi-alpha fitting result

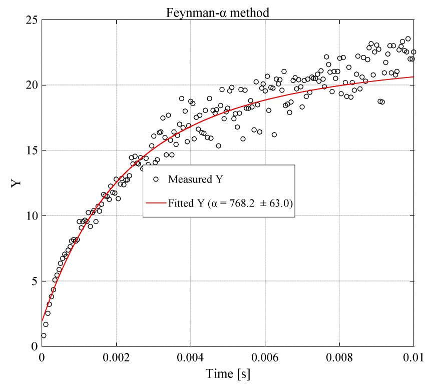

Fig. 3. Feynman-alpha fitting result

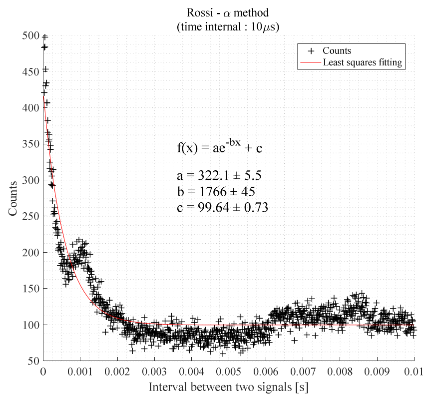

Fig. 4. Advanced Rossi-alpha fitting result

ACKNOWLEDGEMENT: This research was conducted under the collaboration research between UNIST, Korea and Research Reactor Institute, Kyoto University.

CO3-5 Measurement of Bismuth Sample Reactivity Worth in A-core of KUCA for ADS

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INTRODUCTION: The Japan Atomic Energy Agency (JAEA) has investigated neutronics of the accelerator-driven system (ADS) of a lead bismuth eutectic (LBE) cooled-tank-type core to transmute minor actinides discharged from nuclear power plants. For the design study of ADS [1], integral experimental data of nuclear characteristics of LBE is necessary to evaluate the error and uncertainty of cross sections of lead (Pb) and bismuth (Bi). This study aims to measure the Bi sample reactivity worth under the same conditions as the previous experiment for the Pb sample reactivity worth in FY2013 [2].

EXPERIMENTS: The Bi sample reactivity worth was measured by substituting Al plates for Bi ones in test fuel region at the critical state. Here, the reference configuration loaded with Al plates was constructed as the same one as the previous experiment for the Pb sample reactivity worth [2]. In the test fuel region, the number of test fuel assemblies was five, setting around the core central zone of (14, M), (15, L), (15, M), (15, O) and (16, M) as shown in Figure 1.

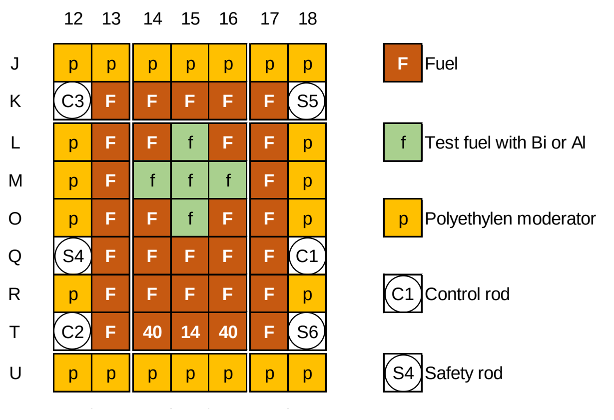

Figure 1 Core configuration of A-core of KUCA for Bi sample reactivity worth experiment

The patterns of Bi sample reactivity worth experiment were summarized in Table 1. In a total number of 40 unit cells of the central test region of fuel rod, two plates of Al (1/16") were substituted for two plates of Bi (1/16") per unit cell. This substitution is quite similar to that of the previous experiment except that the Bi plates were used instead of Pb ones. The Bi sample reactivity worth was estimated through the difference of the excess reactivities between Al reference core and Bi core. In the experiment, the critical state was adjusted by maintaining the control rods in certain positions, and then the excess reactivity was deduced by the difference between the critical and super-critical states in the core. The experimental excess reactivity was obtained by combining with the reactivity worth of each control rod evaluated by the rod drop method and its integral calibration curve by the positive period method.

Table 1 Pattern of Bi sample reactivity worth experiment

Core	Test fuel region				
	(14,M)	(15,L)	(15,M)	(15,O)	(16,M)
Ref.	Al	Al	Al	Al	Al
Case 1	Bi	Al	Bi	Al	Bi
Case 2	Al	Bi	Bi	Bi	Al
Case 3	Bi	Bi	Al	Bi	Bi
Case 4	Bi	Bi	Bi	Bi	Bi

RESULTS: The Bi sample reactivity worth experiment was successfully carried out from the viewpoint of reproducibility of the previous Pb sample reactivity worth experiment [2], since measured excess reactivity of the Al reference cores for the Bi and Pb experiments were comparable in the same condition, as shown in Table 2. The absolute values of Bi sample reactivity worth were experimentally found to be less than those of Pb ones per equivalent volume. The analysis of the results is in progress. A comparative study on Bi and Pb sample reactivity worth would be available to assess qualitatively neutron characteristics of Pb-Bi coolant material in actual ADS experimental facility, with the combined use of experimental and numerical results.

Table 2 Comparison between the results of measured excess reactivities in Bi and Pb cores.

Core	Bi sample (pcm)	Pb sample (pcm) [2]
Ref.	87±1	92±5
Case 1	143±3	186±7
Case 2	165±3	202±8
Case 3	163±3	237±9
Case 4	171±3	248±9

Acknowledgement

This study is supported under the Innovative Nuclear Research and Development Program by the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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Measurement of ^{238}U(n,γ) γ ray from Subcritical System

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INTRODUCTION: In Fukushima Dai Ichi nuclear power plant, so called fuel debris was formed. The fuel debris would be retrieved and enclosed in containers. For the efficient storage of the fuel debris, taking account of negative reactivity by capture reactions of stainless steel (Capture Credit) had been proposed [1]. That is based on the neutron induced gamma ray spectroscopy (NIGS) to obtain reaction rate ratio of the capture to the fission. Additionally, quantification of neutron capture reactions in ^{238}U is also desirable since ^{238}U(n,γ) is one of the most significant reactions in a system where low-enriched U is used. The reaction rate ratio of ^{238}U(n,γ) / fission would be of use to deduce the residual enrichment. In a zero-power critical system, the reaction rate could be obtained by detection of 0.278 MeV γ rays from β decay of ^{239}Np. However, for fuel debris, detection of the γ rays is not practical due to intense background γ rays from fission products (FP) such as $^{134,\,137}$Cs, ^{154}Eu, ^{144}Pr, and ^{106}Rh. Accordingly, we focused on prompt γ ray of 4.060 MeV from ^{238}U(n,γ) [2] since the energy is greater than highest one of long-lived FP γ rays. However, the emission of the 4.060 MeV γ ray is not evaluated in JENDL-4 [3] and the γ ray had never been detected in KUCA-C core where 93%-^{235}U enriched U-Al fuel is loaded [4].

EXPERIMENTS: One of the noise for the measurements of 4.060 MeV γ ray is the prompt fission one, of which intensity is roughly proportional to the amount of ^{235}U. In order to enhance the signal to noise ratio, the average ^{235}U enrichment was reduced to 5.4 % in KUCA-A core by combined use of 93%-^{235}U enriched U-Al with U- alloy plates of natural enrichment. In Fig. 1, the sub-critical set up of 5x5A1/8"p70EUDU is shown. The core was driven by a ^{252}Cf neutron source located center of the fuel. A HP-Ge detector of 20% relative efficiency is used for the γ ray measurement. In order to shield the detector from the neutron irradiation, 7 layers of polyethylene cells were also loaded. The measurement time was 2.5 h.

The overall measured spectrum is shown in Fig. 2. The most prominent peak is of 2.223 MeV γ ray from H(n,γ) reaction. In higher energy region, a photo-electric peak of 7.724 MeV γ rays from ^{27}Al(n,γ) reaction is prominent although count rates of its single and double escape peaks are larger. Between these peaks, continuum spectrum of prompt fission γ rays and small peaks are found. Using the peaks with those of prominent ^{27}Al(n,γ) peaks [5], the pulse height was calibrated. Then a peak spectrum of 4.060 MeV was identified. Since no peak is found in 4.571 MeV, the 4.060 MeV peak is of a photo-electric peak. No significant γ ray emission other than that from ^{238}U(n,γ) is reported in CapGam [5]. According to JENDL-FPY/FPD-2011 [6], γ ray of 4.0617 MeV from ^{90}Rb generated by fission reactions may contribute to the peak of 4.060 MeV. However, the ^{238}U contribution is found greater than 91% in the peak by the count rates of another γ rays (4.135 MeV) from ^{90}Rb. Summarizing the results, we conclude detection of the 4.060 MeV γ ray from ^{238}U(n,γ) reaction is available for sub-critical systems of low-enriched U.

In the measured spectrum, several kinds of γ ray from fission products, such as, ^{88}Br($T_{1/2}$=16.5 s), ^{90}Rb($T_{1/2}$=158 s), ^{91}Rb($T_{1/2}$=58 s) , ^{95}Y($T_{1/2}$=10.3 min), ^{97}Y($T_{1/2}$=3.8 s), ^{136}Te($T_{1/2}$=17.5 s) are observed. The intensity of them is known as a good indicator to infer ratio of fission nuclides [7]. Combining count rates of γ rays from those FPs, ^{238}U(n,γ), and prompt fission, nuclide densities inside the system might be inferred.

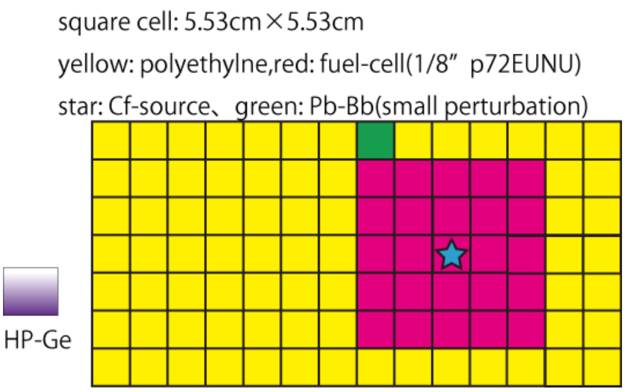

Fig.1 Horizontal geometry of fuel and detector.

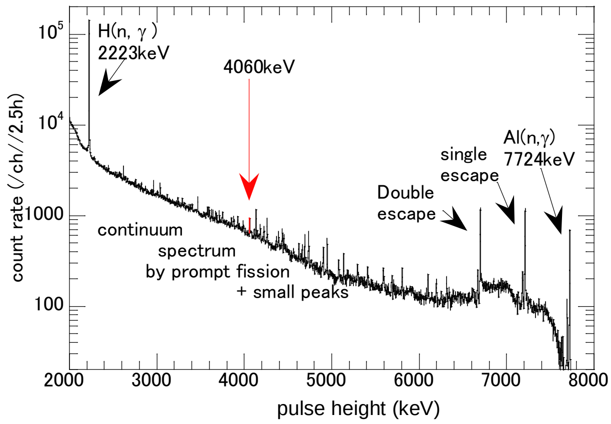

Fig.2 NIGS spectrum obtained in KUCA-C core.

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CO3-7 Development of New Optical Fiber Type Neutron Detector for Reactor Physics Experiments

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INTRODUCTION: Neutron detection technology is one of the key issues in reactor physics experiments. Some specifications, such as the detection sensitivity, the dynamic range and the detector size, are required depending on purposes of experiments. A small size detector is quite useful because it can be easily inserted into a narrow space in an experimental reactor core and make little perturbation to a reactor. We are developing a new optical fiber type neutron detector, which can show a peak shape in a pulse height spectrum [1]. Since this type of detectors has only a small grain of a $Eu:LiCaAlF_6$ scintillator, its sensitivity is quite low. In order to improve the sensitivity, the number of scintillator grains should be increased. A wavelength-shifting fiber (WLSF) could be useful to collect uniformly scintillation photons from a large number of small scintillator grains. In this study, we fabricated a new optical fiber type neutron detector consisting of a small neutron scintillator and a WLSF connected to a clear optical fiber light guide. We, additionally, evaluated the response of the fabricated detector.

EXPERIMENTS: Figure 1 shows the photograph of the fabricated detector. The $LiF/Eu:CaF_2$ eutectic scintillators were used instead of the $Eu:LiCaAlF_6$ scintillator. This scintillator has high light yield comparable to the $Eu:LiCaAlF_6$ and higher Li content. Therefore, the sensitivity is expected to increase compared with the $Eu:LiCaAlF_6$ based detector. Hundreds of small $LiF/Eu:CaF_2$ scintillators were attached on the side surface of the WLSF with transparent resin. Scintillation photons are absorbed in a core of the WLSF, re-emitted as wavelength-shifted photons and then transferred in the core region of the WLSF. Since the attenuation length of the WLSF is not so long, the WLSF is connected with a clear optical fiber to effectively transmit wavelength-shifted photons to the photomultiplier tube. Signals from the photomultiplier tube was fed into a digital multichannel analyzer. In order to confirm basic operation of the fabricated detector, we irradiated it with neutrons emitted from a ^{252}Cf source and moderated by the polyethylene. We also tested the fabricated detector at Kyoto University Critical Assembly (KUCA).

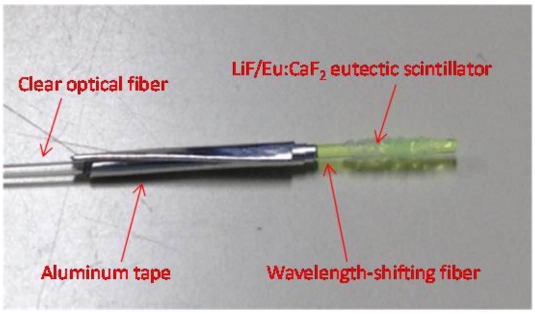

Fig. 1 Photograph of the fabricated optical fiber type neutron detector. The detector consists of small pieces of $LiF/Eu:CaF_2$ eutectic scintillators, a wavelength-shifting fiber connected with a clear optical fiber and a photomultiplier tube.

RESULTS: Figure 2 shows the pulse height spectrum obtained from the fabricated detector when it was irradiated with ^{252}Cf neutrons. Although the scintillation photons were transmitted through an optical interface between the WLSF and the clear optical fiber, a clear peak shape corresponding to neutron events can be seen in the spectrum.

Finally, we confirmed a normal operation of the detector when it was placed in a core of the KUCA. Figure 3 shows the relationship of the signal count rate between the fabricated and the reference detector. The linear relationship was experimentally confirmed.

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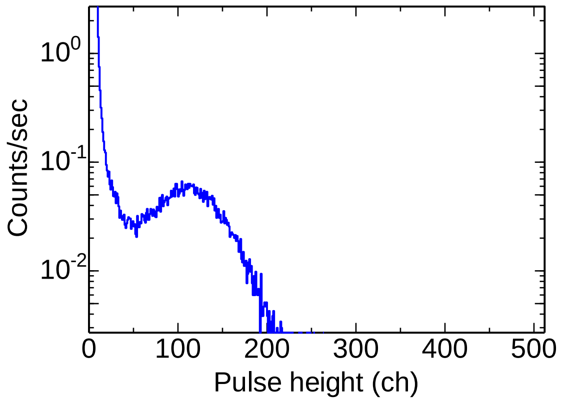

Fig. 2. Pulse height spectrum obtained from the fabricated detector.

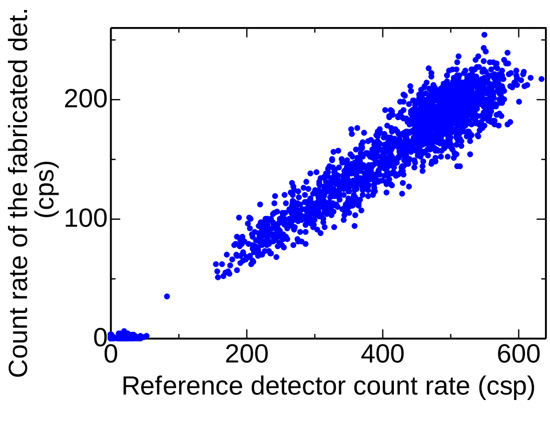

Fig. 3. Relationship of the signal count rate between the fabricated and the reference detector.

CO3-8 Measurement of Fundamental Characteristics of Nuclear Reactor at KUCA (II)

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ACKNOWLEDGEMENTS: This study was performed under the cooperation of the following researchers:

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INTRODUCTION: International Research Institute for nuclear Decommissioning (IRID) is developing criticality control techniques for fuel debris removal in Fukushima Daiichi nuclear power plant.

Sub-criticality monitoring system is to detect criticality approach for each step of debris removal operation by neutron noise analysis using Feynman-alpha method. A prototype of the sub-criticality monitoring system was tested to verify applicability on various sub-criticality measurement conditions.

Soluble and insoluble neutron absorbers are to prevent criticality of fuel debris. To prove ability of neutron absorption, reactivity worth was measured and compared to simulated prediction for each neutron absorbers.

EXPERIMENTS (Sub-criticality measurement): Three H/U types of core condition corresponding to high (H/U235=322), middle (H/U235=107), and low (H/U235=54) were configured in KUCA B-core. Target k-eff varied from 0.7 to 0.95 by adjusting fuel bundle numbers for each H/U core condition. Three B-10 type neutron detectors connected to the prototype system were set in several horizontal distances from core. The distances varied from 0 to 60 [cm] with or without polyethylene between detectors and core. The prototype system, which is set in the control room of KUCA, acquired time list mode data of neutron pulse. A measuring time was about 30 minutes for each case. The time list mode data were analyzed by an off-line PC using Feynman-alpha method. Then, k-eff was evaluated from the analyzed prompt neutron decay ratio (alpha) and calculated prompt neutron life time.

RESULTS: The results are shown in Fig.1. The prototype system showed the measurement error of k-eff within almost 10% for the condition that the k-eff is above 0.7. It was found that H/U affected the measurement error relatively small. In contrast, the distance between core and detectors affected the measurement error large. The upper limit of measurable distance was found to be below 20 [cm] with polyethylene.

EXPERIMENTS (Reactivity worth measurement): A representative H/U (H/U235=107) core was configured in KUCA-B core. Insoluble neutron absorbers (sintered metal/B_4C, B- and Gd-containing glass, Gd_2O_3 particles, liquid glass/Gd_2O_3 powder, and resin/Gd_2O_3 powder) were put in each Al cases (50×50×14 mm). The case was set in center of the core. Reactivity worth was measured by neutron source multiplication method. Soluble neutron absorber (sodium pentaborate) was also measured in the same way.

RESULTS: The results of insoluble neutron absorbers are shown in Fig. 2. C/E were 1.0～1.3 and show good agreement except for the Gd_2O_3 particles.

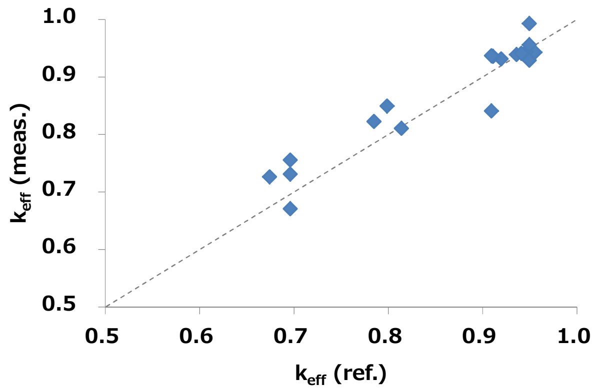

Fig.1 Comparison of measured and reference k-eff for sub-criticality monitoring

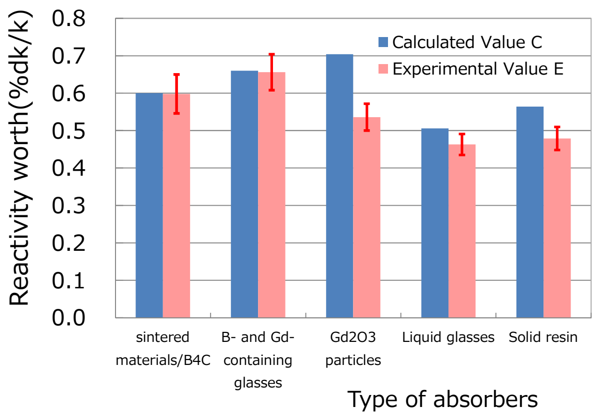

Fig.2 Comparison of measured and calculated reactivity worth for insoluble neutron absorber

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CO3-9 Baisc Nuclear Characteristc Measurements at Subcritical Core

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INTRODUCTION:
Subcriticality monitoring system has to be used to detect criticality approach for each step of debris removal in Fukushima Daiichi nuclear power plant. For this purpose, International Research Institute for nuclear Decommissioning (IRID) is developing criticality control techniques for fuel debris removal based on neutron noise analysis using Feynman-alpha method. A prototype of the sub-criticality monitoring system was tested to verify applicability on various sub-criticality measurement conditions.
Usually, noise measurement has been carried out by detecting neutrons, however, gamma-ray detectors were also used in this experiments to analyze gamma-ray noise analysis.

EXPERIMENTS
Three H/U types of core condition corresponding to high (H/U235=322), middle (H/U235=107), and low (H/U235=54) were configured in KUCA B-core. Target k-eff varied from 0.7 to 0.95 by adjusting fuel bundle numbers for each H/U core condition. Three B-10 type neutron detectors connected to the prototype system were set in several horizontal distances from core. The distances varied from 0 to 60 [cm] with or without polyethylene between detectors and core. The prototype system, which is set in the control room of KUCA, acquired time list mode data of neutron pulse. A measuring time was about 30 minutes for each case. By detecting gamma-ray, $LaBr_3$ scintillation detectors whose energy resolution is much higher than a NaI(Tl) detector were used to discriminate gamma-ray emitted from certain gamma-ray source.

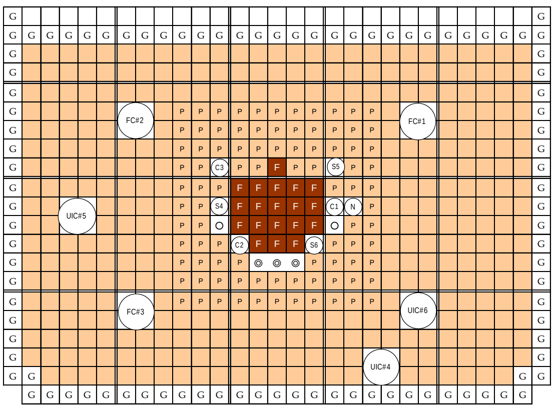

Fig.1 Core configuration of B-core

RESULTS: Figure 2 shows gamma-ray energy spectrum measured by a $LaBr_3$ detector at top of fuel assembly. It is found that gamma-ray emitted from neutron capture reaction of hydrogen is clearly discriminated from other gamma-ray.
Gamma-ray signal only from hydrogen capture reactions were acquired time list mode data acquisition system and analyzed according to normal Feynman-alpha method to obtain subcriticality. Figure 3 shows results of Y-value at low subcritical state (keff=0.95) and it can be fitted to theoretical formula based on Feynman-alpha method. Prompt neutron decay constant was 913.0±360.1 (s^{-1}). On the other hand, prompt neutron decay constant obtained by neutron detection by a He-3 detector was 979.8 (s^{-1}), which means that gamma-ray noise analysis method can be used in subcriticality monitoring system. However, in large subcritical state (keff=0.7), measured Y-values were fairly scattered and cannot be fitted to theoretical formula.

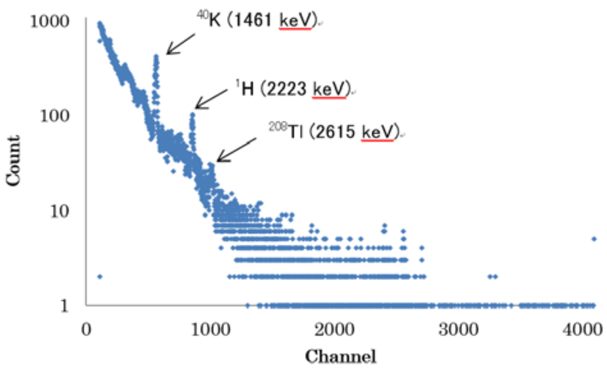

Fig.2 Gamma-ray energy spectrum by $LaBr_3$ detector

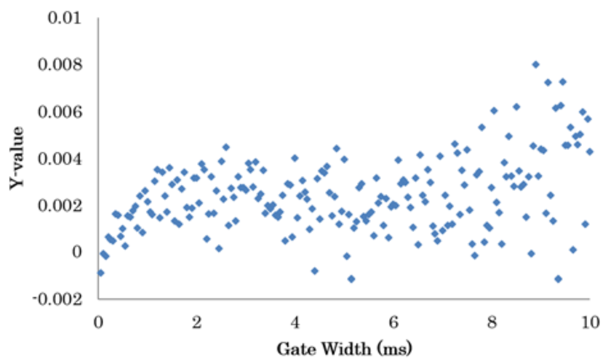

Fig.3 Results of Y-value by gamma-ray noise analysis